A State of the Art Review on High Water Mark (HWM) Determination

Abstract

The High Water Mark (HWM) is an important cadastral boundary that separates land and water. It is also used as a baseline to facilitate coastal hazard management from which land and infrastructure development is offset to ensure the protection of property from storm surge and sea level rise. The determination of the HWM has a long history. Its definition, the mean and even the corresponding determination methods have changed through time. In addition, the location of the HWM is difficult to define accurately due to the ambulatory nature of water and coastal morphology variations.

To better understand the HWM determination, this paper reviews the development of the definition of HWM, including ordinary high water mark (OHWM), mean high water mark (MHWM), mean high water spring (MHWS) and mean higher high water (MHHW), and the existing HWM indicators, such as vegetation line and beach morphological features. Two common methods of HWM determination, field survey and remote sensing, are discussed in this paper. This is followed by the investigation of the possible factors that influence the variation of the HWM position. Furthermore, an overview of the ambulatory nature of both water and coastal morphology, which contributes to the difficulties in HWM determination, is provided. Finally, the limitations of previous determination methods and future direction in HWM determination studies are also discussed. This study concludes that it is necessary to develop a robust analytical system to identify, evaluate and integrate various factors into the process of determining the HWM.

Keywords: *High Water Mark; Mean high water; Tide; Coastal boundary; Shoreline capture; Coastal management*

1. Introduction

The determination of the High Water Mark (HWM) is important for coastal management and planning as the HWM is considered as a cadastral boundary to separate land and water (Whittal, 2011). It is used to denote public and private land, and as a reference from which development is offset to limit the exposure of properties to potential coastal hazards.

However, the HWM is one type of water and land boundary, which is not explicit. The definitions of the HWM are ambiguous and can be interpreted in different ways (Clerke, 2004; Coutts, 1989). For example, in a statutory definition, the use of the term ‘ordinary’ in OHWM (Ordinary High Water Mark) as applied in tidal waters is not mathematically ideal (Horlin, 1994) and is not part of the tidal lexicon (Mahoney, 2009b). Therefore, the interpretation of the word ‘ordinary’ has altered since its earliest inception, and the HWM position defined by OHWM varies over time and space.

Multiple methods have been developed to determine HWM, and can be categorised into two groups: tidal datum-based HWM and onshore HWM indicators. However due to different research or practical purposes, the nature of study areas and data availability, the suitability of methods can vary. Currently only limited research has been done to systematically review these methods from both theoretical and practical perspectives.

This paper aims to conduct a state of the art review of HWM determination. It starts with a review of fundamental concepts such as the definition of HWM and the indicators for HWM determination. Then suggestions on HWM determination method selection in different situations and gaps in industry practices are provided, which is followed by difficulties in HWM determination and future directions for further study. A significant outcome of this study will provide practical insights into the HWM determination.

2. Development of the HWM Definition

2.1. Development of the Legal Definition of the HWM in Common Law

The use of tidal measurements to delineate the seaward extent of private land is well established in common law (Clerke, 2004; Cole, 2007; Horlin, 1994; Maloney and Ausness, 1974a). The origin of the law can be traced back to the sixteenth century during the reign of Queen Elizabeth I, when Thomas Digges, a lawyer, engineer and surveyor, first cited the theory of royal ownership of foreshore areas (Cole, 1997). According to Digges, the land beneath tidal waters and the foreshore, which is the submerged land of the kingdom, should be held by the Crown (Maloney and Ausness, 1974a). In seventeenth century England, Digges's theory was revived by the treatise of Lord Mathew Hale, who declared that the foreshore 'between the high water mark and the low water mark' belonged to the Crown (Maloney and Ausness, 1974a).

However, in early law, there was no clear definition of the HWM. While Hale's doctrine firmly established ordinary high water mark (OHWM) as the boundary between privately-owned property and public beach (Clerke, 2004; Cole, 2007; Horlin, 1994; Maloney and Ausness, 1974a); the definition in his doctrine incorrectly equated the concept of 'neap tides' with 'ordinary tides', leaving the definition ambiguous.

In 1854, the OHWM was clarified in common law by a case in which it was defined as 'the average of the medium tides in each quarter of a lunar evolution during the year (in which the line) gives the limit, in the absence of all usage, to the rights of the Crown on the seashore' (Cole, 1997). In the following years, this common law model and definition of OHWM was widely adopted by most of the United States (U.S.) and commonwealth countries such as Australia, for delineating property boundaries (Gay, 1965; Hamann and Wade, 1990; Humbach and Gale, 1975; Landgate, 2009; Maloney, 1977; Simon, 1993). The OHWM is also considered synonymous with the term 'the line of mean high water mark (MHWM)' (Coutts, 1989; Horlin, 1994; Land Services, 2008; Maloney and Ausness, 1974a).

2.2. The Mean and Ordinary High Water Mark

In areas with tidal variations, Gay (1965) suggested that ordinary or mean high water mark should apply as the boundary between privately owned uplands and the submerged lands, which are subject to public ownership. In order to locate MHWM accurately, survey regulations in New Zealand require a record of tide information over a period of 370 days (Kearns, 1980). This is particularly important in areas with seasonal tidal change, where a mean annual height of high water is appropriate (Cole, 1997). In contrast, Gay (1965) insisted that a period of nineteen years as appropriate for the determination of MHWM at any given place, as it takes into account most of the significant tide constituent effects (Australian Hydrographic Service, 2010; Doodson, 1921; Pawlowicz et al., 2002). Thus, the time span to calculate mean high water (MHW) is not fixed but it is apparent that the more tide information that is collected, the more precise will be the MHW.

Mean high water is defined as the average height of all high water marks over a long period of time (The Intergovernmental Committee on Surveying and Mapping (ICSM), 2012). It can be interpreted in different ways (Clerke, 2004; Coutts, 1989). Interpretations are complicated by certain tidal characteristics and conditions.

There are three possible types of tide (Gill and Schultz, 2001): diurnal, semidiurnal and mixed. A tide is considered semidiurnal when there are two high and two low tides within a single day; whereas a diurnal tide has only one tidal cycle per day. A mixed tide is similar to the semidiurnal tide; however the two high waters and low waters, occurring daily, have significant differences in height. Thus, technically, the term 'mean high water spring' (MHWS) applies only to those areas with a semidiurnal type; while the term 'mean higher high water' (MHHW) is applicable in mixed and diurnal waters (Pugh, 1996). Generally, the definition of MHWS is the average of all high water observations at the time of the spring tide over a period of time (The Intergovernmental Committee on Surveying and Mapping (ICSM), 2009). Whereas, MHHW is the mean of the higher of the two daily high waters over a period of time (The Intergovernmental Committee on Surveying and Mapping (ICSM), 2009).

Land and property administrative organisations use different interpretations of the HWM to define land ownership boundaries. Hicks (1985) points out that both MHW and MHHW can be interpreted as property boundaries between privately-owned uplands and publicly-owned tidelands. In the U.S., each State has adopted MHW and mean lower low water (MLLW) as the boundary delimiting privately and publicly owned land. The exceptions are the states of Hawaii, Louisiana and Texas, which consider that MHHW provides a more reliable datum for surveying and engineering purposes (Cole, 2007; Fowler and Treml, 2001) (Figure 1). Similarly in Australia, boundaries are defined in two main ways: MHW in South Australia (Land Services, 2008) and New South Wales (Clerke, 2004), and MHWS in Queensland (Collier and Quadros, 2006; Dunphy, 2010) and Western Australia (Landgate, 2009).

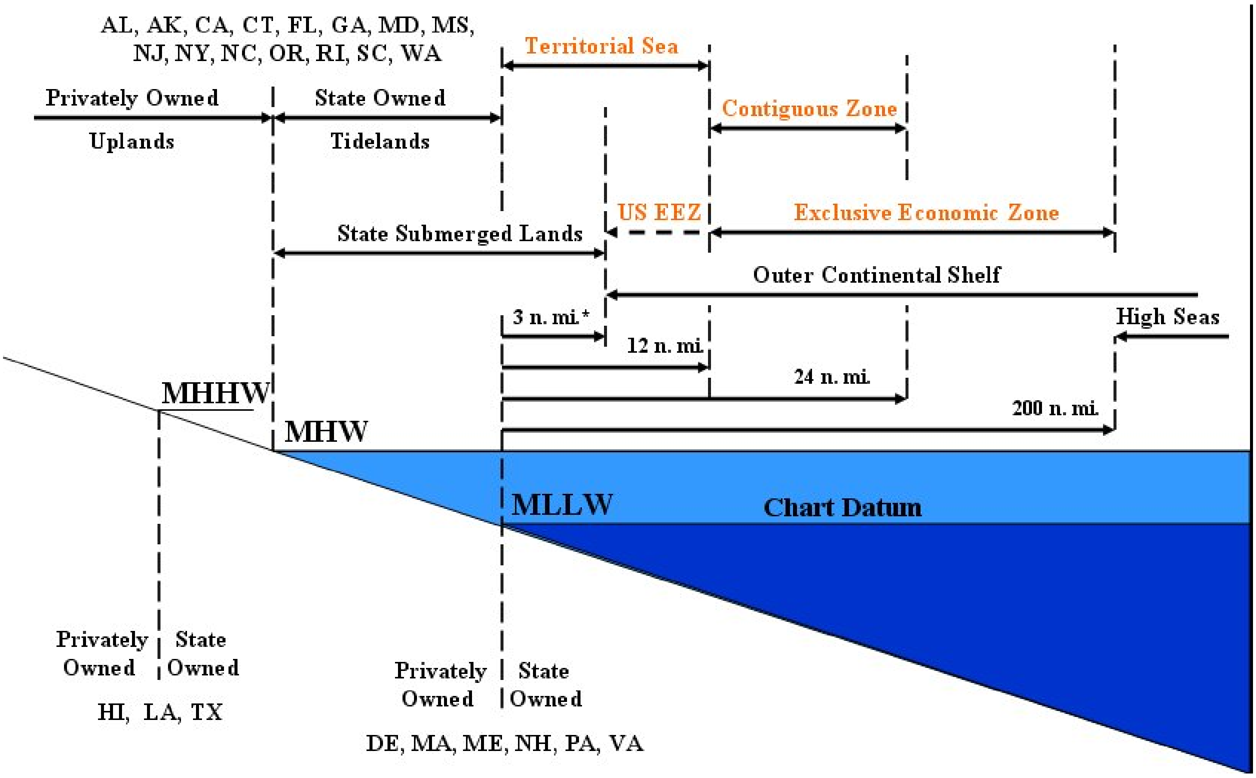

Figure 1 The extents of the U.S. maritime zones (National Oceanic and Atmospheric Administration, 2012)

In Western Australia, the statutory definition of the HWM is the ordinary high water (OHW) at spring tide. This is generally accepted as equivalent to the definition of MHWS in the Australian National Tide Tables (Landgate, 2009). The height of MHWS is defined as ‘the average, throughout a year when the average maximum declination of the moon is 23.5 degrees, of the heights of two successive high waters during those periods of 24 hours when the range of the tide is greatest’ (Department of Defence, 2008). However, because the Western Australian coast also experiences diurnal and mixed tidal characteristics (Pattiaratchi and Sarath Wijeratne, 2009), the MHHW is correspondingly applied (Figure 2).

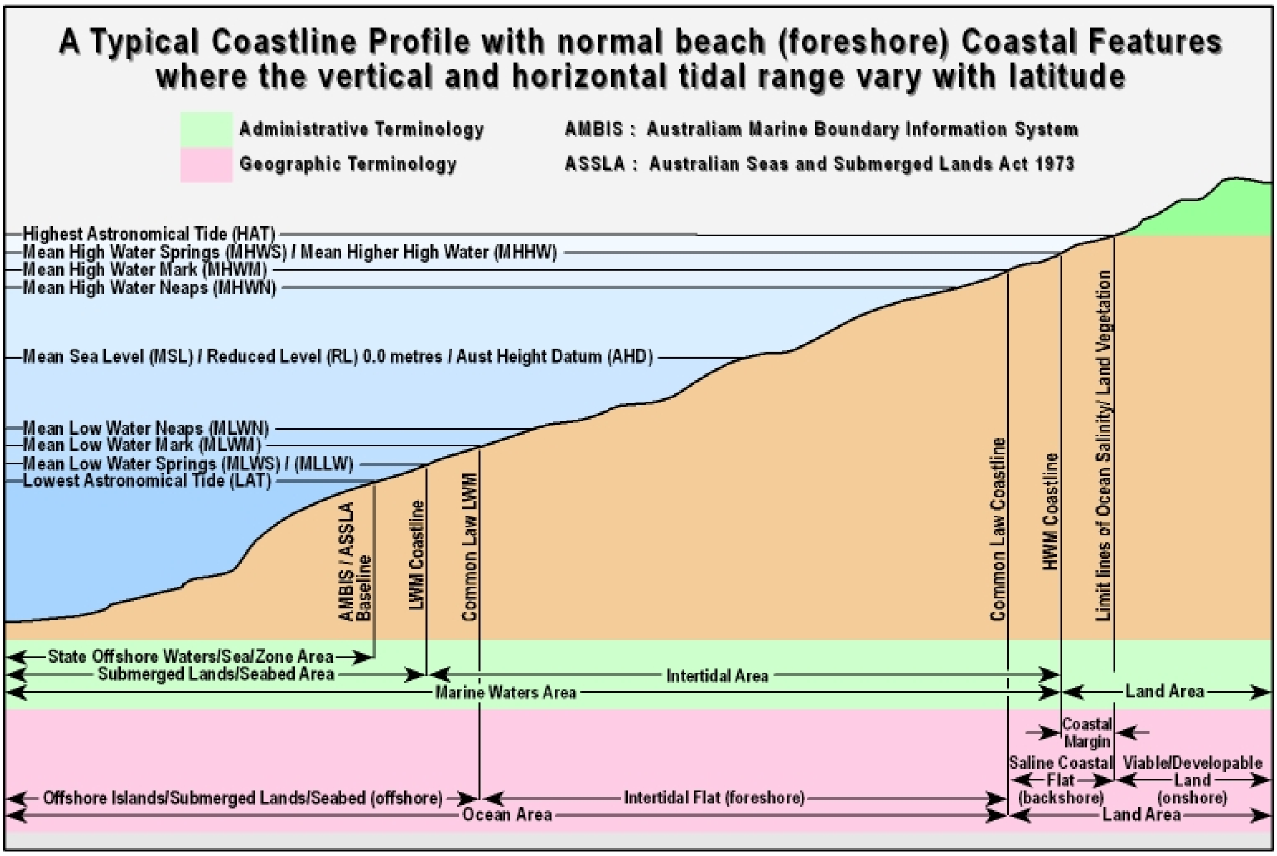

Figure 2 HWM determination concepts (Fenner, 2010)

The HWM using mean or ordinary high water is not consistent even in the same location. This is because the OHW, defined as ‘the average of the medium tides in each quarter of a lunar evolution during the year’ (Cole, 1997), may be lower than the MHW in normal situations. Furthermore, the time span for calculating ordinary and mean high water is not necessarily the same.

Authorities who are responsible for defining the coastal boundaries have gradually adopted MHW as being equivalent to the OHW, as defined under English common law (Horlin, 1994). This approach has become widely accepted because the definition is less ambiguous. Nevertheless, because the category of private property is defined as the land above the position of lands beneath tidal waters, there is not yet a consensus as to whether MHW can represent the ‘true’ landward boundary of tide water. This question remains unanswered and requires further evaluation. Furthermore, the meaning of ‘high water’ or ‘high tide’ has not been definitively addressed (Briscoe, 1983). This continues to be a key issue and is fundamental to HWM determination.

The HWM, including the tidal datum-based HWM, should usually be related to a recoverable datum (Clerke, 2004). Normally, mean sea level is used as such a reference point (Gay, 1965). In Australia, the Australia Height Datum (AHD) is adopted (Landgate, 2009), as the establishment of the AHD is equal to mean sea level (between 1966 to 1968 at 30 tide gauges around the coast of the Australian continent) at its initial establishment (Mahoney, 2009b).

3. Statistical Methods for HWM determination

3. 1. Harmonic Analysis and Tidal Datum Computations

The development of tidal analysis, especially harmonic analysis, provides a full description and sufficient information for tidal datum determination (Pugh, 1996). Harmonic tidal analysis was introduced by William Thomson in the 1860s (National Oceanic and Atmospheric Administration (NOAA)), and was further elaborated by Darwin (1883) and Doodson (1921).

Harmonic tidal analysis considers the tidal datum as a sum of the constituent cosine waves (Australian Hydrographic Service, 2010; Foreman, 1977; Phillips; The Virginia Institute of Marine Science):

$$H\left(t_i\right) = h_0 + \sum_{j=1}^{m} A_j \cos\left[2\pi\left(\sigma_j t_i - \phi_j\right)\right] \tag{1}$$

$H\left(t_i\right)$ represents the tidal height at time *i*; h_0 is the height of mean sea level; *m* is the number of constituents chosen for the particular area; A_j, σ_j and ϕ_j represent the amplitude, frequency and phase of constituent *j*, respectively. Since the frequency of every constituent is known in advance, the formula demonstrates that the key to harmonic analysis and constituent calculation is to calculate the amplitude and phase of the individual constituent cosine curves.

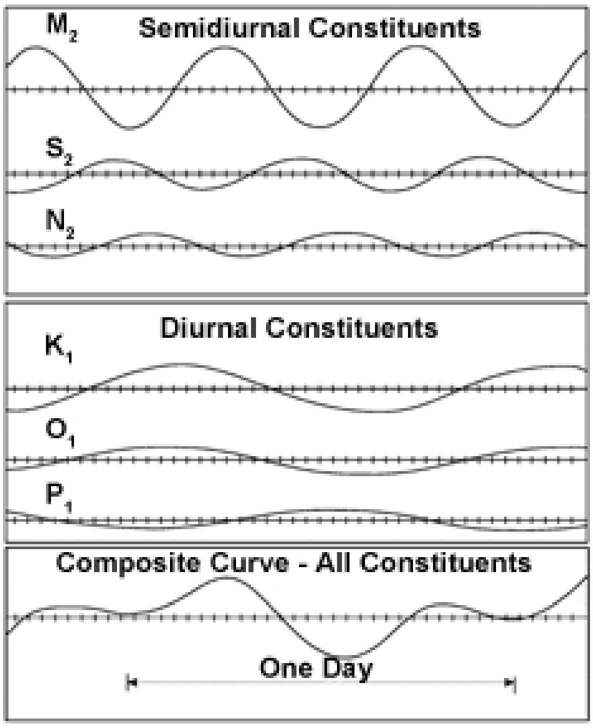

Figure 3. Sum of tidal constituents (Department of Oceanography, 2007)

Two methods are commonly used together to calculate these elements: Fourier analysis (Korner, 1989; Phillips, 1999) and the least squares technique (Foreman, 1977). The summary of the calculation process is (1) to transform the $\sum_{j=1}^{m} A_j \cos\left[2\pi\left(\sigma_j t_i - \phi_j\right)\right]$ as $\sum_{j=1}^{m}\left[C_j \cos\left(2\pi\sigma_j t_i\right) + S_j \sin\left(2\pi\sigma_j t_i\right)\right]$ in which

$$2\pi\phi_j = \arctan S_j / C_j \qquad (2)$$

$$\text{and } A_j = \left(S_j^2 + C_j^2\right)^{1/2}; \tag{3}$$

(2) to apply the least squares technique and minimise

$$\sum_{i=1}^{n}\left[y\left(t_i\right)-h_0-\sum_{j=1}^{m}\left[C_j\cos\left(2\pi\sigma_j t_i\right)+S_j\sin\left(2\pi\sigma_j t_i\right)\right]\right]^2$$

where *n* represents the number of observed tidal recordings and $y\left(t_i\right)$ is the tidal height at time t_i.

Once the value of S_j and C_j are determined, ϕ_j and A_j can be calculated by the Equations 2 and 3.

In an analysis of 146 constituents, 45 reflect the astronomical arguments while the remaining 101 constituents are commonly referred to as the shallow water constituents (Cartwright and Edden, 1973; Foreman, 1977).

The astronomical constituents are considered the main components and represent the periodic variation at a certain relative location of the sun, earth and moon (National Oceanic and Atmospheric Administration (NOAA)); while the shallow water tidal constituents are produced by the interaction of the main tidal constituents when the tide enters shallow water and is affected by bottom friction (Foreman, 1977; The Intergovernmental Committee on Surveying and Mapping (ICSM), 2010). The shallow water constituents distort the normal tidal profile, and at some sites the distortion can be significant (Foreman, 1977). Therefore, a long period of tidal observation (greater than 19 years) is suggested to take into consideration all the possible shallow water effects.

To determine which constituents are the most significant (each site has its own energy signature), the Rayleigh comparison constituent method can be used (Foreman, 1977), although in general, of 146 constituents, only 37 of them are considered major constituents (National Oceanic and Atmospheric Administration (NOAA)). Furthermore, four major constituents are most important (Equation 4): K_1 is the diurnal principal declination tide; O_1 is the diurnal principal lunar tide; M_2 is the semidiurnal principal lunar tide; and S_2 is the semidiurnal principal solar tide. S_2 and M_2 are the basic sun and moon tides, whereas K_1 and O_1 are the main effects of the declination of the sun and the moon (Horlin, 1994).

Besides calculating the tidal datum, the application of these four constituents also includes quantitatively analysing the type of tides by calculating their ratio (Dietrich and Kalle, 1963; Foreman, 1977):

$$F = (K_1 + O_1) / (M_2 + S_2) \tag{4}$$

F is called the form number. The tide can be precisely classified as follows:

i. Semidiurnal if $0 \le F \le 0.25$,

ii. Mixed if $0.25 < F \le 3.00$,

iii. Diurnal if $F > 3.00$.

Statistical methods are well-established approaches often used to determine tidal datums using long-term tidal records and are considered an objective way to determine coastal boundaries (Boak and Turner, 2005). This is because statistical methods usually observe the tide over a considerable period of time, thereby taking a number of necessary factors into account (Gay, 1965). Cole (1997) stated that the method of using tidal datum records is the best approach to determine the position of the HWM, especially where landform change over a period of time is insignificant. The most popular statistical method is to calculate the ‘mean’ tidal datum over a period.

For surveys to locate the position of the tidal datum-based HWM for one site, especially at a standard port (also known as a ‘primary port’) for which sufficient tidal data is available (The Intergovernmental Committee on Surveying and Mapping (ICSM), 2009), the tide tables such as Australian National Tide Tables (ANTT) in Australia, can be consulted. These tables provide the information of tidal constituents (Land Services, 2008), which are essential to calculate the tidal datum-based HWM. The relevant tidal datums are derived as follows (The Intergovernmental Committee on Surveying and Mapping (ICSM), 2009):

$$MHWS = Z_0 + (M_2 + S_2) \tag{5}$$

$$MHHW = Z_0 + (M_2 + K_1 + O_1) \tag{6}$$

where Z_0 represents the mean sea level (MSL). For practical purposes, the MSL is equivalent to an AHD value of 0 metres in Australia (Horlin, 1994). The equations illustrate that the tide is actually the composite sum of factor constituent cycles, which usually last 18.6 years (Cole, 1997). During this time, all the major tidal variations have been taken into account (Gay, 1965), excluding only those in extreme conditions (Center for Operational Oceanographic Products and Services, 2003; Clerke, 2004).

3.2. The HWM Defined by Department of Transport (DoT), Western Australia

Besides the most common definitions of the HWM, the methods of determining the position of the HWM varies across both jurisdictions and also between responsible authorities within the same jurisdiction. One height suggested by the Department of Transport (DoT), Western Australia (WA), was obtained from experienced surveyors' long-term observation of the shoreline features as well as tide and wave effects on the coastal area.

Don Wallace, the former Chief Hydrographic Surveyor at the DoT, introduced a method to calculate lower low tide (LLT) following many years of experience as a surveyor (Mahoney, 2007). The term, lowest low water (LLW) was not used to describe a lowest low tide level. A LLW is considered to be an extreme low water caused by severe weather conditions. From all of his in-the-field experience, Wallace realised that even the most complex analysis of tidal data did not necessarily provide a result, which imitated the lower low tide levels that could easily be observed. An Indian spring low water zero or a lowest astronomical tide zero was just not low enough.

Being a hydrographic surveyor, he sought a practical solution that was applicable to all of the tide regimes within Western Australia, one that was based on sound statistics and enhanced, for the time being, by empirically determined factors. Since the methodology and the results were consistent with his visual on-site observations he knew that his scheme would provide a foundation for future research. He suggested that LLT is equal to the 19th low water occurrence from the cumulative frequency in the approved 19-year epoch of tide height observations, minus 1.5 times the standard deviation of the residuals (Equation 7).

$$\text{LLT} = 19^{\text{th}}\ \text{Low Water Occurrence} - 1.5\sigma \qquad (7)$$

Note:

- A residual value results from the observed tide minus the predicted tide from constituents' analysis method.

- The '$-$ 1.5σ' lowers the low water occurrence.

The higher high water (HHW) can be calculated by using the mirror image of Wallace's formula (Equation 7). This HHW height could be adopted as the position of the HWM (Mahoney, 2007):

$$\text{HHW} = 19^{\text{th}}\ \text{high water occurrence} + 1.5\sigma \qquad (8)$$

Note:

- The '+ 1.5σ' raises the high water occurrence.

This method has the advantage of operating independent of tide types, and it takes into account the signal noise caused by factors, such as cyclones (Wood, 2005). The limitation of this approach is that the method was determined only on the water side and ignores the effect of localised geomorphology, thereby isolating the water and land for HWM determination.

Early surveyors rarely used statistical methods to determine the HWM based on the tide datum, especially those who had no knowledge of tides (Clerke, 2004). After statistical methods have been widely applied, it shows that water level can be objectively predicted by tide information in some areas. However, offsets still exist between the tide gauge records and the actual positions that water reaches on the shore because the tide gauge excludes the influence of wave runup. This situation will be exaggerated on gently sloping sandy beaches, making it difficult to transform a tidal elevation to the horizontal position of MHM (Morton and Speed, 1998; Pajak and Leatherman, 2002). Also, an accurate statistical method is not available when distant from tide gauges, as the estimation of tidal information can only be reached by interpolation methods (Greenfeld, 2002). Furthermore, the tidal datum-based statistical method isolates the water from the land, which ignores local spatial information, such as geomorphology and its variation through time.

The HWM, depending on its usage and the way it is measured and defined, can be divided into two types: vertical and horizontal HWM. The tidal datum-based HWM belongs to the vertical HWM category. However, the HWM is not always tied to a specific high water height; sometimes a boundary that represents the HWM is mapped as a horizontal line between buildings or land features (Mahoney, 2009a), and can be called HWM indicators.

4. HWM indicators

When tidal information is unavailable or insufficient, land surveyors prefer to use field evidence to establish the position of boundaries to separate private from public ownership (Morton and Speed, 1998). A number of indicators are available, which can be used to delineate the HWM. Normally, the delineation process involves evaluation of a combination of various different indicators (Office of the State Engineer, 2007).

The area between the vegetation line and the berm crest (usually the highest spot on a coastal berm) is defined as the beach (Bauer and Allen, 1995; Rooney and Fletcher, 2000). Correspondingly, most features lying on the beach, such as scum or an oil line left on the shore and the debris or fine shell continuously deposited on the berm or foreshore (Briscoe, 1983), can be considered HWM indicators and can be viewed as a natural representation of the horizontal HWM. These physical markings indicate the general HWM line attained by the runup of high water (Hicks et al., 1989; Simon, 1993; Williams-Wynn, 2011). However, these indicators tend to be present only for short periods and are not present on every beach. These physical indicators also include the impact of wave runup.

Previous studies considered several other common types of HWM indicators in addition to tidal records, including the boundary between dry and wet sand, referred to as the high water line (HWL) (Moore et al., 2006), dune toe (Williams-Wynn, 2011) and the seaward limit of vegetation (Williams-Wynn, 2011). These shoreline features are good indicators of water level and are therefore sometimes used as boundary indicators between land and water (Coutts, 1989; Gay, 1965; Maiti and Bhattacharya, 2009; Moore, 2000; Morton and Speed, 1998). Admittedly, not all of these indicators are available on all coastlines, and choosing which to use for a specific area generally depends on the physical coastal characteristics and data availability (Boak and Turner, 2005).

4.1. High Water Line

Unlike morphological features, the HWL is the intersection of land with a water surface at its highest point (Hicks et al., 1989), and therefore it is the best indicator of the water-land interface (Crowell et al., 1991). HWL is generally located landward of the last high tide (Anders and Byrnes, 1991; Crowell et al., 1991; Shalowitz, 1964; Stockdon et al., 2002) and seaward of the berm during normal weather and tidal conditions (Morton and Speed, 1998; Pajak and Leatherman, 2002).

In the past, HWL was identified by the visible signs of ‘high tides’ and the discoloration of sand or rocks on the shore (Boak and Turner, 2005; Shalowitz, 1964). Nowadays, with the development of remote sensing technology, HWL is defined as the line separating dry and wet beach and can be identified in aerial photographs by the sudden change of colour (Moore, 2000; Morton and Speed, 1998). However, Pajak and Leatherman (2002) mentioned that there might be more than one high water line left on the beach; the previous days' marks are sometimes still visible, so the most recent high water line needs to be surveyed in the field. Fortunately, the previous marks are often not as clear as the recent one and the contrast is different. Although, McBeth indicates that even when a HWL is exposed to the sun after the tide recedes, it will remain stable on the beach (Boak and Turner, 2005; McBeth, 1956).

The offset between the position of MHW and HWL as identified in the field and on aerial photographs has been identified as insignificant (Crowell et al., 1991; Shalowitz, 1964). By contrast, other scientists argued that the relationship between these two can only be interpreted as being correlated to each other, and that HWLs seldom coincide with the MHW or the berm crest (Morton and Speed, 1998). The MHW is normally seaward of the HWL because of wave runup, (Morton et al., 2004; Moore et al., 2006; Pajak and Leatherman, 2002; Ruggiero et al., 2003; Ruggiero and List, 2009). This phenomenon is more significant on flat beaches, where even the high water lines themselves are likely to change significantly day by day (Morton and Speed, 1998; Pajak and Leatherman, 2002).

Although HWL is easily identified on the shore and is convenient to use as an indicator, its position is not stable, especially on gently sloping beaches (Pajak and Leatherman, 2002). Also, the position of HWL usually corresponds to coastal morphology, water level and wave characteristics (Morton and Speed, 1998).

4.2. Vegetation Line

The vegetation line is a biological feature established by either regular floods of water or storms that destroys the existing vegetation (Morton and Speed, 1998; Shalowitz, 1964). Therefore, the vegetation line indicates the position of high water in some way. Parker (2003) states that the vegetation line and most geomorphological indicators are landward, away from the mean high water line. The vegetation line was also chosen as an indicator for marine boundaries because it is the most stable natural boundary, controlled by the wash associated with extreme high water (Guy Jr, 1999; Priest, 1999).

Usually, the vegetation line appears in two positions: one is the inland dense vegetation, and the other is young and sparse, lying on the back shore. The dense vegetation is considered a more stable boundary indicator than the sparse vegetation (Morton, 1974); most storm surges cannot reach the position beyond it (Morton and Speed, 1998). This makes the vegetation line the most landward water boundary. However, in some wetlands where plants require continuous wash to survive, the vegetation line is seaward of the high water line and lower in elevation (Shalowitz, 1964).

There are two disadvantages to using vegetation lines as a marine boundary. First, this line is easily subject to artificial manipulation, either intentionally or unintentionally. Second, sometimes a vegetation line is irregularly and/or indistinctly distributed along the shore and is difficult to identify (Morton and Speed, 1998). Although drawbacks exist with the vegetation line, it is still an important indicator of the HWM location.

4.3. Beach Morphological and Biological Features

Other coastal features that could indicate the position of the HWM include cliff edge, berm crest and frontal dune toe. The cliff edge is the best evidence of where a horizontal HWM should be, and there should be no conflict about land in these areas (Crowell et al., 1991). However, cliffs are only one type of shoreline. Morton (1998) argued that the berm crest is the best physical evidence of the location of OHWM associated with wave runup. Pajak and Leatherman (2002) indicate that the HWL will not be highly dynamic in its position when a well-defined berm exists, as it stops the landward swash to some extent. However, this feature is not very apparent on every coast and may disappear in extreme situations (Hsu et al., 1989). Cole even suggested using biological indicators as water boundaries (Cole, 1997); for example, the top of oysters appearing on a pier shows where the MHW is located (Songberg, 2004), but the accuracy of this has not been proven. Compared with these indicators, the dune toe is more common and relatively stable on most coasts, and MHW usually exists to the waterside of the frontal dune (Coutts, 1989).

4.4. Water Level

The use of water level to delineate coastal property boundaries has its roots in Roman civil law, in which the coastal boundary was not defined in terms of daily tide, but rather in terms of water level. This definition might be because the Mediterranean Sea, where Roman civil law code developed, has a minimal daily tidal range and is dominated by the effect of wave runup (Cole, 2007). Such definition has been formally adopted by some countries whose legal system is based on Roman civil law, such as Puerto Rico, in which the upland limit of public property is considered to be reached by the great storm wave (Cole, 2007).

In South Australia, the MHWM contour is sometimes set out by observing the water edge and the information from a nearby tide gauge at the appropriate time (Land Services, 2008). However, as indicated in Morton and Speed's (1998) study, the actual water level is systematically underestimated by tide gauges due to the exclusion of wave runup, and this results in the property boundary position increasing the area claimed by the upland owners. Similarly, HWL may represent the previous position of high water but may not indicate the most recent maximum runup limit (Boak and Turner, 2005). Thus, the following questions remain:

- Should water level that includes the runup be used as a coastal boundary?
- Can MHW or HWL be equivalent to the water level and if not;
- Is there any shoreline feature that can represent the position of the water level?

4.5. HWM Determination based on the spatial continuity of swash or tidal probability (SCSP or SCTP)

Boak and Turner (2005) suggested that when attempting to determine shorelines more accurately, researchers have not considered all the indicators, and this has impacted results. Furthermore, the landside and waterside information is always used separately to determine the HWM position. This ignores the fact that water and land are one integrated system for HWM determination. For example, the spatial distribution of swash/tidal probability, which is the chance of inundation on the beach face over a specified time period, is a significant criterion for determining HWM position and it is commonly ignored.

Swash/tidal probability at different locations along one beach profile (cross-section) tends to be spatially autocorrelated, which means two locations nearby along a profile tend to have similar swash probability compared with those that are farther apart (Cliff and Ord, 1970). However, for two locations, such autocorrelation only takes effect within a certain distance. This is called the range or spatial continuity distance, which can be estimated by the basic moment of geostatistics—the semivariogram (Jian et al., 1996; Oliver and Webster, 1990).

Two new methods to determine HWM by integrating both land and water information were introduced in recent studies (Liu et al., 2012; Liu et al., 2013). The methods determine the position of the HWM based on the spatial continuity of swash probability (SCSP) or spatial continuity of tidal probability (SCTP) for a range of HWM indicators that are either land-based or water-based. The water information refers to the cumulative distribution of swash (wave runup) and tidal heights abstracted from long-term records of wave and tide information; while the land information is indicated by the spatial relationship among the HWM indicators derived from image analysis of aerial photographs and digital elevation models (DEM).

Although every HWM indicator has its drawbacks, each indicator shows the potential position of the HWM based on one particular purpose or viewpoint.

5. HWM data collection methods

One of the challenges in coastal studies is to develop a methodology and procedure to determine the coastal boundaries with available data that is sufficiently repeatable and robust (Boak and Turner, 2005). The process of determining the HWM can involve two approaches:

- Select a definition of the HWM and choose the appropriate indicators or datum to calculate the HWM with the available data; and
- Detect the location of the HWM on the field or in the imagery with spatial information.

Methods used to collect the HWM data can generally be divided into two groups: survey methods and remote sensing methods.

5.1. Survey Methods

Because the HWM is self-evident at particular times, HWMs can be obtained by marking the water's edge, HWL and vegetation line in a field survey (Nunley, 2002). This is the most convenient method, as the physical line on the ground can be easily observed (Cole, 1997). Although the HWM location can be observed through these physical features, the certainty in its horizontal position is very weak (Hirst and Todd, 2003). It is in the order of metres, or even tens of metres if the terrain is close to horizontal. As such, the accuracy of the surveyed position is limited by the knowledge of the position of the feature, rather than limited by the survey instrumentation and methods used. Modern survey field techniques can rapidly determine positions on the ground to a centimetre or less using Real-Time Kinematic (RTK) based Global Navigation Satellite Systems (GNSS) or electronic angle and distance measuring equipment (total stations). As a boundary or real property, the HWM is understood to be an ambulatory (moving) boundary and is temporal. A survey today does not determine the extent of rights to land and seashore tomorrow. It is also understood that the location of the HWM is not to the order of accuracy that other fixed boundaries are located due to the nature of the boundary.

Field survey work is not limited to determining coastal features. After determining the height of the HWM at a tide gauge, the HWM contour value in close proximity to that gauge can be set out by spirit levelling from a nearby benchmark related to a recoverable datum—such as AHD in Australia. Landgate (Western Australian Land Information Authority) in WA recommend it as good survey practise to determine the HWM (Landgate, 2009) based on the assumption that MHW is a contour (Cole, 1997). Clerke (2004) stated that the mean high water boundary levelling from the tidal elevation should follow the contour on the foreshore. However, the HWM is only a 'contour' when in close proximity to the tidal control station (Mahoney, 2009b), since the actual elevation of the HWM may vary over longer distances. In WA, a similar type of survey method was introduced by Cribb and Horlin (Mahoney, 2009b) and is considered a practical and convenient way to determine the position of the HWM. Cribb and Horlin (Mahoney, 2009b) determined the general height of the HWM relative to national datum (AHD) in major ports based on many years of field observations and reviews of hard-copy tide records. Surveyors at Landgate can thus survey the vertical HWM directly on the beach.

However, this is generally a labour- and time-consuming method for getting data of long segments along the shore with sufficient resolution and density, and the value will also vary depending on the nature and slope of the coast. The popular use of GNSS provides rapid measurement of onshore features, and it is moderately inexpensive to monitor both horizontal and vertical positions of onshore features (Guariglia et al., 2006; Mitasova et al., 2002; Morton et al., 1993; Uunk et al., 2010). Also, the coast is usually a suitable area to conduct GNSS surveys because of the unobstructed view of the sky (Morton et al., 1993). However, the point capture method by GNSS cannot cover large areas in a short time.

5.2. Remote Sensing Methods

Since the 1920s, aerial photography and photogrammetric methods have been used to determine marine boundaries and document topographic information along coasts (Anders and Byrnes, 1991; Crowell et al., 1991; Overton et al., 1996; Stockdon et al., 2002). Surveyors have also used their judgment to accept certain topographic features on the photographs as the position of the HWM (Horlin, 1994). These works often include manual interpretation of photography (Boak and Turner, 2005; List and Farris, 1999) together with field surveys, including shoreline feature analysis, the testimony of eye witnesses and sand colour analysis (Cole, 1997; Nunley, 2002). For instance, Crowell *et al* (1991) stated that HWL as an indicator of the land-water interface is a line that can be detected by the change in colour or grey tone in aerial photographs caused by differences in the content of the sand. Similarly, Anders and Byrnes (1991) asserted that HWL could be recognised by wet/dry contact on a beach caused by an abrupt or subtle change in contrast. The wet/dry line on aerial photographs was considered as the most prominent feature dividing land and water by Cole (1997). One definition that enhanced the edge detection was the zone of variance of high-pixel brightness in imagery (Shoshany and Degani, 1992). A more common and practical method is for the analyst to detect the shore markings on photography by the last preceding high water (Pajak and Leatherman, 2002; Shalowitz, 1964) and its accuracy is dependent on photography being taken at high tide. Furthermore, the location of salt-resistant marshes and mangroves shown on aerial photographs are also used as indicators of the HWM in the U.S. (Clerke, 2004; Horlin, 1994).

However, many studies show that interpreting marine boundaries from photography introduces significant errors in locating shorelines (Anders and Byrnes, 1991; Boak and Turner, 2005; Moore, 2000; Pajak and Leatherman, 2002; Stockdon et al., 2002). Hirst and Todd (2003) argued that it is difficult to determine the high tide line on a beach within a few metres using ground-based observations, and even more so from a plane using aerial photographs. Crowell *et al.* (1991) wrote that errors in determining coastal boundaries from aerial photography arise from two processes: (1) identification or interpretation of the boundary, and (2) mapping the interpreted line as part of topographic information.

Compared with field surveying, manual interpretation of shoreline features as HWM indicators may be less accurate and more subjective because it relies heavily on the photogrammetrist's individual skills and judgement (Anders and Byrnes, 1991; Boak and Turner, 2005; Crowell et al., 1991; McBeth, 1956), and so the method cannot guarantee precise determination of the HWM. Also, precise boundary detection depends on high quality aerial photography (Boak and Turner, 2005). When one cannot see the water boundary clearly because of poor contrast or a fuzzy transitional zone of tonal change, it is difficult to determine the exact location of HWM indicators (Crowell et al., 1991).

Satellite imagery taken by remote sensing techniques is an alternative to aerial photography. It has also been widely applied in coastal boundary determination. Both MHW and MLW can be located by the satellite imagery using an infrared band which can detect wet and dry sand (Horlin, 1994), while another potential application of satellite imagery is to detect biological profiles (Clerke, 2004; Cole, 1997). Because of flooding, wind or other effects, vegetation zones can be distinct on the shore and indicate the high water level in an extreme situation. Thus, it is helpful to look at vegetation information by enhancing the 'vegetation band' to help detect vegetation lines (Nunley, 2002).

However, the degree of utility is questionable. This is because modern satellite images such as SPOT and Landsat have large ground cell sizes of more than 1 metres; therefore, they show no potential for accurately identifying the shoreline features (Nunley, 2002). However, this does not mean that even good quality satellite images will necessarily result in a satisfactory boundary. Sometimes large scale high resolution data can also make it difficult to obtain a well-defined boundary to delineate objects because the overly finely distributed details make it difficult to distinguish the target classes from others during the classification process (Burrough and Frank, 1996). This is called the ‘salt-and-pepper effect’ (Blaschke et al., 2008). Therefore, the result of traditional pixel-based image analysis is unsatisfactory for shoreline feature detection using high-resolution imagery (Antunes et al., 2003).

The identification of shoreline features on both satellite images and aerial photography can become more objective when using unsupervised classifications such as neural networks that distinguish land and water classes (Boak and Turner, 2005; Kingston et al., 2000). However, there is no unanimous agreement about how to make a consistent interpretation of features when applying remote sensing techniques (Pajak and Leatherman, 2002).

Airborne Light Detection And Ranging (LiDAR) systems are optical remote sensing techniques that are mainly used to measure dense clouds of three dimensional data, including topography (Mitasova et al., 2002; Stockdon et al., 2002). Airborne LiDAR techniques can be used to capture onshore features over large areas in a short time frame (Armaroli et al., 2004), thus it is a complementary technique used to fill data gaps between ground profiles. Moreover, when applied in a repetitive manner, LiDAR enables three-dimensional analysis of temporal beach profile variations.

With the use of LiDAR topographic data, it is possible to create a DEM of the foreshore, with which a tidal datum-based HWM can be easily identified (Boak and Turner, 2005; Hapke and Richmond, 2000; Morton et al., 2004). More potential applications of LiDAR-derived DEMs for studying coastal morphology have been illustrated in studies by Hapke and Richmond (2000) and Mitasova et al. (2002). Landgate in Western Australia recommend the use of modern survey equipment, such as LiDAR (Landgate, 2009), especially when it is necessary to obtain data on a broad shore, and quickly obtain data over a large area (Boak and Turner, 2005). However, this does not mean the HWM position obtained from LiDAR is 100% reliable. The nature of the beach, such as its morphology, and the resolution of the data captured by this technique also influence the precision of the determined HWM indicators (Stockdon et al., 2002). This may contribute to the variation in the determined HWM position.

In conclusion, the spatial information of shoreline features indicating the position of the HWM can be captured by a number of methods. Field surveys using Real-Time Kinematic (RTK) based Global Navigation Satellite Systems (GNSS) receivers are considered the most accurate determination tool. However the method is labour- and time-consuming when collecting high-resolution data along long segments of the shore. Also, the value of the data, in terms of accuracy, will vary depending on the nature and slope of the coast. In contrast, aerial photography interpretation offers substantial time and labour savings. However, if the aerial photography is of poor quality, precise boundary detection is not possible. The optical remote sensing imagery technique enables the unsupervised process and the precision of the features captured is enhanced. However, the process of classifying shoreline features using high resolution images may result in overly finely distributed classification results on the classified image (Blaschke, 2010; Dragut and Blaschke, 2006; Marpu, 2009; Walter, 2004), which makes identification of shoreline features difficult using traditional supervised or unsupervised classification methods. Table 1 summarises the advantages and disadvantages of different HWMs and their capture methods.

Table 1. Comparison among different HWM definitions from their advantages, disadvantages and capture methods

	Advantages	**Disadvantages**	**Capture methods**
Ordinary high water mark (OHWM)	It is the earliest definition of HWM and has been well clarified in common law.	It is not mathematically ideal (Horlin, 1994) and is not part of the tidal lexicon (Mahoney, 2009b).	Long-term tidal records.
Mean high water mark (MHWM)	It takes into account the seasonal tidal variation (Cole, 1997) and most of the significant tide constituent effects (Australian Hydrographic Service, 2010; Doodson, 1921; Pawlowicz et al., 2002)	The time span to calculate MHWM is not fixed.	Long-term tidal records.
Method developed by Department of Transport, Western Australia (Section 3.2)	Operates independent of tide types, and takes into account the signal noise caused by factors, such as cyclones (Wood, 2005).	This method ignores the effect of localised geomorphology, thereby isolating the water and land for HWM determination	Long-term tidal records.
High water line (HWL)	It is the best indicator of the water-land interface (Crowell et al., 1991)	There might be more than one high water line left on the beach (2002) and its position is not stable, especially on gently sloping beaches (Pajak and Leatherman, 2002).	Field survey; photograph; remote-sensing imagery
Vegetation line	It is the most stable natural boundary, controlled by the wash associated with extreme high water (Guy Jr, 1999; Priest, 1999).	It is easily subject to artificial manipulation, either intentionally or unintentionally. In addition, sometimes a vegetation line is irregularly and/or indistinctly distributed along the shore and is difficult to identify (Morton and Speed, 1998).	Field survey; photograph; remote-sensing imagery
Beach Morphological and Biological Features	They are very easy to be identified and there should be no conflict about land in these areas if such evidences exist (Crowell et al., 1991)	These feature are not very apparent on every coast and may disappear in extreme situations (Hsu et al., 1989)	Field survey; photograph; remote-sensing imagery; DEM
Water level	It takes into account the great storm wave (Cole, 2007).	Inconsistent measures exist between water level and nearby tidal gauge (Morton and Speed 1998).	Field survey
The spatial continuity of swash probability (SCSP) or spatial continuity of tidal probability (SCTP)	These methods integrate water and land as one system when determining the HWM and consider the spatial distribution of swash/tidal probability (Liu et al., 2012)	The high-resolution imagery and DEM required by the calculation of SCSP and SCTP are not available at every coast (Liu et al., 2012).	Long-term tidal and wave records; remote-sensing imagery; DEM

6. Difficulties in HWM Determination

Traditionally, MHWM was determined using medium- to long-term tidal records (Cole, 2007). Although determined with mathematical precision, the MHWM using a tidal datum is not suitable as a permanent boundary for property rights (Cole, 1997) because neither the ocean level nor the coastal geomorphology are stationary over long periods. The HWM is difficult to determine accurately due to the ambulatory nature of both water and coastal morphology (Whittal and Fisher, 2011).

The HWM is considered ambulatory, that is, it may shift over time both horizontally and vertically because of artificial or natural factors. Tide is produced by the gravitational forces of the moon and sun, but additional non-astronomical factors such as cyclones, air pressure, artificial structures, wind, wave height, types of coast, sea level change, and El Niño and La Niña are factors that may influence the position of the HWM (Dolan et al., 1980; Hicks et al., 1989; Moore, 2000; Morton and Speed, 1998; Pajak and Leatherman, 2002). To determine the unbiased position of the HWM, long-term observation of tides and waves can identify most of the above factors and include them in statistical calculations.

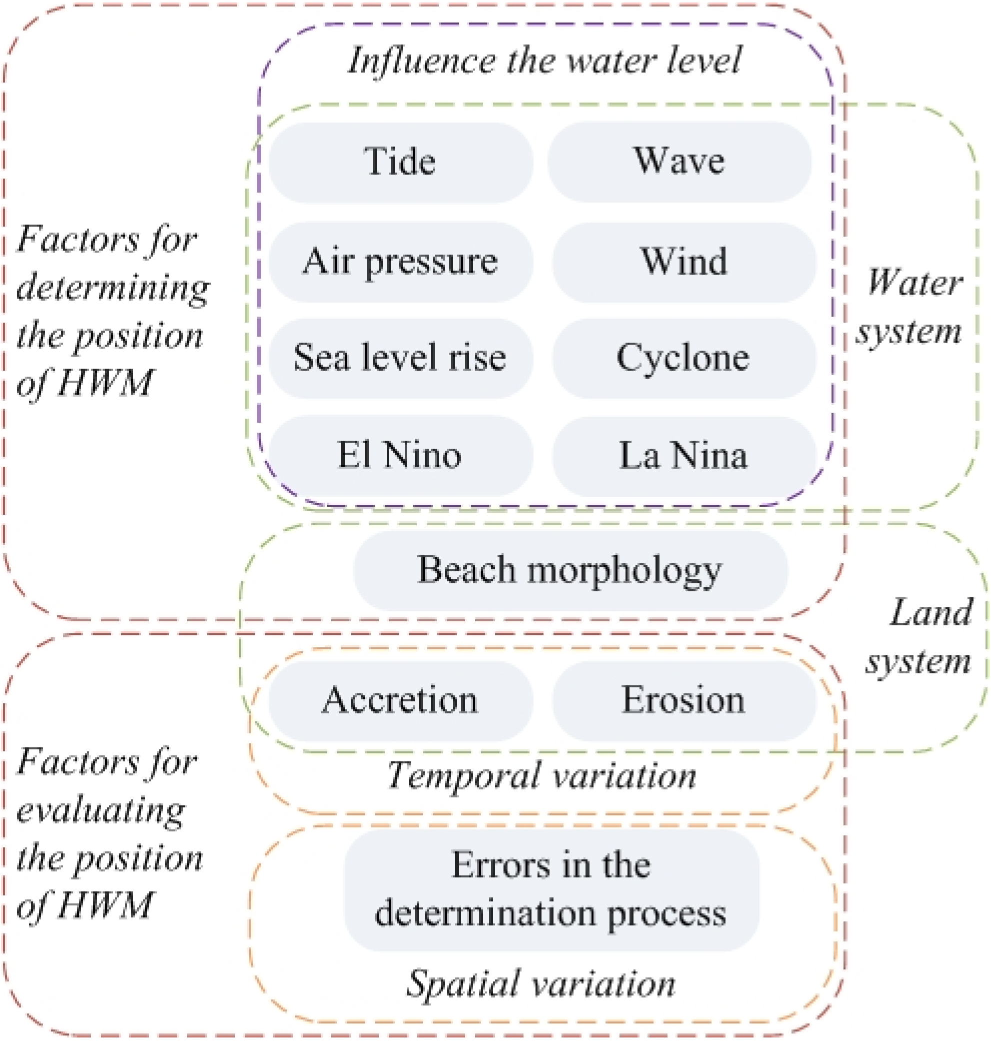

Figure 4 The factors influencing the position of the HWM and its relation to the determination process

The aim of HWM determination coincides with delineating the coastal boundary. When the HWM is defined vertically, it is possible to derive its horizontal HWM position on the coastal zone or in the imagery with spatial information. This means that, to some extent, a transformation can be used to derive one form of HWM from another. However, the two may be inconsistent; for instance, the State Cadastral Data Base (SCDB) in Western Australia (at certain locations) has large offsets between the equivalent horizontal location of HWM defined by height (vertical 'position') and the displayed location of HWM defined as a horizontal boundary (horizontal position). Even if the vertical position of a tidal datum-based HWM is determined by the long-term observation of tides and waves, its horizontal position may vary through time as the coastal morphology changes (Figure 4). Recently, as the development of geography information sciences (GIS) and remote sensing (RS) technology, the evaluation of spatial and temporal variation of shoreline position becomes not as difficult as before. Parameters indicating the variation of shoreline positions like End Point Rate (EPR) (Thieler et al., 2009), Hausdorff distance and even the simulation of beach morphology variation by Monte Carlo (Liu et al., 2013) are able to be easily calculated by the digital shoreline analysis.

The difference between the tidal datum and its equivalent horizontal location is an important topic in marine science (Cole, 1997). Even though the tidal datum may be constant over years in a certain location, the intersection of this datum with data representing the coastal morphology, such as DEM, might be ambulatory (Figure 5) as the coastline changes by eroding or accreting (Coutts, 1989). Therefore, the horizontal location of a tidal datum on a beach should be related to a specific time (Cole, 1997).

Besides the uncertainty of the tidal plane, the slope of shore land is another factor causing significant offsets between the tidal datum and its horizontal location on the beach (Center for Operational Oceanographic Products and Services, 2003; Clerke, 2004). The vertical tidal datum error may lead directly to uncertainty in determining the horizontal HWM (Clerke, 2004). This situation will be exacerbated on relatively flat coastal areas, and a centimetre of difference can cause an extension of many metres horizontally (Center for Operational Oceanographic Products and Services, 2003; Clerke, 2004; Morton et al., 2004). Thus, defining a coastal boundary in gently sloping beach areas and quantifying the spatial uncertainty and variation are difficult research issues that should be addressed (Clerke, 2004; Quadros and Collier, 2008).

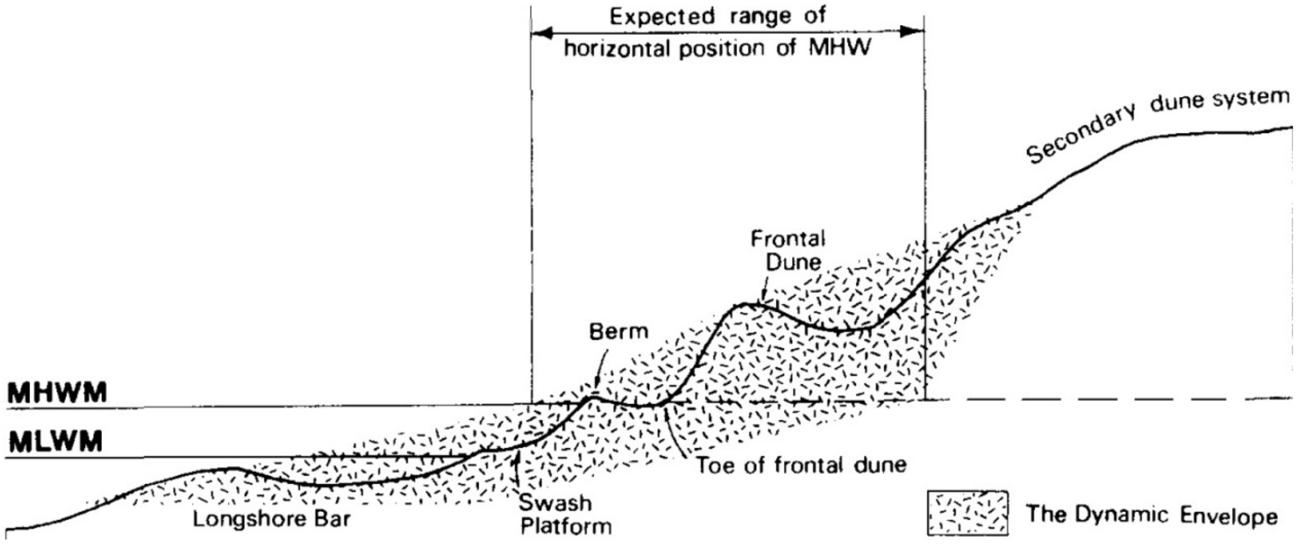

Figure 5 Illustration of the horizontal variation of the tidal datum on the beach (Coutts, 1989)

Changing depth, width and the course of estuaries, as well as the distance from the ocean, are all relevant to the variation of the tide datum (Cole, 1997). The dynamic nature of seawater continuously affects the coast in the form of waves and tides, but these also act variously on different kinds of coast (Anthony and Orford, 2002). Comparing results from study areas with different coastal features can reveal how coastal types may influence the position of the HWM.

7. Further direction of HWM determination studies

The position of HWM indicators varies with the prevailing wind and wave conditions in different areas. Crowell *et al.* (1991) and McBeth (1956) pointed out that the difference between MHW and high water indicated by physical features is minimal for mapping purposes in moderate weather. However, an American case study showed that the MHHW line calculated by tidal signals was located many miles seaward of a boundary determined by physical features on the beach (Cole, 1997). Morton and Speed (1998) also estimated that the actual water level reach on the beach was higher than predicted from the nearby tidal gauges. This indicates inconsistencies in the different definitions of the HWM, which are mainly due to the wave runup effects. Therefore, the question of whether wave runup should be included in HWM determination is left unanswered.

The use of tidal records ignores wave runup and, as such, will always underestimate the HWM in coastal regions (Whittal, 2011). For example, in areas where there is a small tide range and significant wave action, the actual landward water level will be further inland than the HWM level determined using only tide records due to the effects of setup and wave runup. The effect of wave runup in HWM determination has rarely been quantitatively assessed. Yet some studies have indicated that the water level (swash or wave runup) is more appropriate for the HWM used for coastal hazard planning, while the tide water is suitable for coastal property management (Bellomo et al., 1999; Maloney and Ausness, 1974b).

If this is the case, further quantitative analysis is required to evaluate all the indicators based on this assumption. However, analysis is often impeded by limited data because of either wave buoy breakdowns during cyclones or computing problems. As a consequence there are many gaps in the wave information records, and these are not always small gaps (Kalra and Deo, 2007). Moreover, because of the complexity and uncertainty of wave generation, it is difficult to interpolate and model wave information using deterministic equations.

The HWM is recognised as the boundary separating private and public property rights under normal water conditions (Gay, 1965). Coutts (1989) also acknowledged that the HWM can be used to confer ownership of land, where the land stops and the sea begins. Such a definition, including OHWM, MHWM, MHHW and MHWS, is determined from a land property management point of view, and does not take into account the effect of wave runup. Such tidal datum-based HWM determinations, as mentioned before, have their roots in the development of common law for property boundary delineation.

Coastal hazards are any phenomena that threaten coastal structures, property and the environment under extreme weather and water conditions. Coastal hazard planning aims to minimise these risks or hazard (Short and Hogan, 1994). The origin of measuring the water level, which includes the effect of wave runup, or the features indicating the water level to determine the position of the HWM, can be traced back to Roman civil law (Cole, 2007). The U.S. Federal Emergency Management Agency (FEMA) calls this type of HWM ‘wave runup coastal HWM’. FEMA identified this water level to improve disaster preparedness and prevent future hazards (URS Group Inc., 2006). The effect of wave runup, which is of particular interest to coastal emergency planners (Papathoma and Dominey-Howes, 2003), was also analysed for coastal hazard protection by Bellomo et al. (1999). Most of the time when coastal boundaries are analysed for hazard planning purposes, the wave runup height is one of the most important criterion of these studies (Hubbert and McLnnes, 1999; Short and Hogan, 1994).

Thus, the use of HWM can be divided into two different purposes, property management and hazard planning. The major difference between the two is whether the effect of wave runup on the tidal datum plane is included or excluded.

Due to inconsistencies in the definition, there are no reliable techniques nor generally accepted methods to determine the HWM worldwide or even in Australia (Clerke, 2004; Cole, 1997). Therefore, the analysis of various HWM data (called HWM indicators), along with analysis of the methods of determination of the horizontal position of the HWM, is required. This would inform future data collection (tidal datum, terrain morphology, etc.) and data processing (statistical, survey calculations, processing of remote sensing) phases of large-scale HWM mapping. It is likely that, from a better understanding of data and processing, a formal definition for the HWM can be derived for Australia and countries with a similar legal system and understanding of the boundaries of coastal rights.

Indeed, Landgate has been involved in several disputes over the last few years involving the need to defend the definition of water boundaries in Western Australia’s Spatial Cadastral Database (SCDB). Users need to be fully aware of the limitations of the SCDB for precise boundary definition on the one hand, and on the other hand, precise and up-to-date land and water boundary information is essential, but may not be easy to obtain for either property management or coastal hazard planning purposes.

Boak and Turner (2005) suggested that researchers have not considered all indicators in their methods for determining shorelines. The same can be said of HWM determination, and this has affected results. However, the fundamental question of the relationship of each HWM indicator to the water-land interface is still not resolved. Further knowledge of how to integrate the water and land system as a whole and how to define the water-land interface is required. For instance, MHW has been recognised as a concept isolated from the whole coastal system; however, besides knowledge of tides, it is also important to understand the geomorphology of the coast to locate the HWM (Coutts, 1989).

Although LiDAR DEMs have proven useful in coastal studies, some researchers have identified a low accuracy of data in various applications (Bater and Coops, 2009; Hodgson and Bresnahan, 2004; Hodgson et al., 2005). This is most significant with data captured when the technology was first introduced. Therefore, data collection protocols and proper spatial interpolation methods are needed to fill in data gaps.

An acceptable method of determining coastal boundaries should satisfy the following criteria: repeatable, consistent and reliable (Leon and Correa, 2006; Pajak and Leatherman, 2002). Moreover, as an administrative boundary, the HWM tends to be used as though it has been precisely defined (Burrough and Frank, 1996). A cliff edge was considered a much more stable boundary than the instantaneous HWL and berm crest on a beach (Moore, 2000; Morton, 1991); and if conditions permit, these stable features should be given priority as indicators when determining the HWM.

Morton and Speed (1998) point out that, although the determination of MHW considers most of the factors influencing its position over a long period, it is not as stable as a vegetation line, but the higher precision makes it as good an indicator option as the vegetation. However, quantitative analysis and comparison of the variation for each HWM indicator in one system has not been conducted; thus more research on this topic is required. Even if the factors that influence the determination of the HWM were identified and quantified, a rule for the criteria to evaluate the HWM indicators would also be necessary to make a final decision about the proper position of the HWM for different purposes.

Contemporary research has failed to develop a robust method of determining the HWM because of the continuous changes in tidal levels together with unimpeded wave runup, as well as the erosion and accretion of beaches. This explains, in part, why there is no official or widely recognised definition of the HWM. It is important to identify, evaluate and integrate various factors into the process of determining the HWM, yet there is currently no consensus as to how to do so.

8. Conclusion

The determination of the HWM has a long history. Its definition, the mean and even the corresponding determination methods have changed through time.

Nowadays, no consensus has been reached on the definition of the HWM worldwide, due to the diversity of coastal types, different determination purposes and the limitations of observation techniques and data. The definition of the HWM is different among different countries as their legal systems and the understanding of rights in the coastal zone, and especially the shoreline, are different. Advantages and disadvantages exist in different definitions, and the corresponding capture methods vary among different HWM definitions. There are a number of factors influencing the position of the HWM. Moreover, the land and water systems have always been considered separately, which leads to inconsistent results in the determination of land/water boundaries from the water-side and land-side.

Therefore, an improved method to determine the position of the HWM is required. This should be an analytical system that integrates all factors. In addition to the HWM position determined by the improved methods, all HWM indicators should be assessed in one evaluation system that can provide a consistent and robust HWM determination methodology.

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